# β–NMR Spectrometers at TRIUMF

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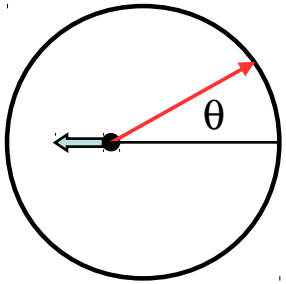
CMMS

*KEK-TRIUMF workshop on Ultra Slow Muons 2012.3.8-9*

# Beta-detected NMR

β-NMR facilities at ISAC are optimized for studies in condensed matter physics, extracting information via the anisotropic beta-decay of spin-polarized radioactive ions (*i.e.*, $^{8}$Li) implanted into materials.

$$^{8}\mathrm{Li} \Longrightarrow {}^{8}\mathrm{Be} + e^{-} + \nu_{e}$$




$^{8}$Li:
Spin=2
Quadrupole moment Q =33 mb
$\gamma$ = 6.3 MHz/T
decay anisotropy <A>=-1/3
lifetime $\tau$= 1.2 s

**High sensitivity** is due to signal detection via nuclear decay and high beam polarisation ~70%, generated by co-linear optical pumping.

**Low beam energy,** ~30keV at source, which can be altered with simple electrostatic optics. Also, very small energy spread ~2eV.

**A depth-resolved probe** suitable for experiments in physics of surfaces, over a range of ~5 – 500nm, generally applicable to study of *any* phenomena at surfaces of bulk materials, within thin film structures and interfaces which affect the polarisation of the implanted probe spins.

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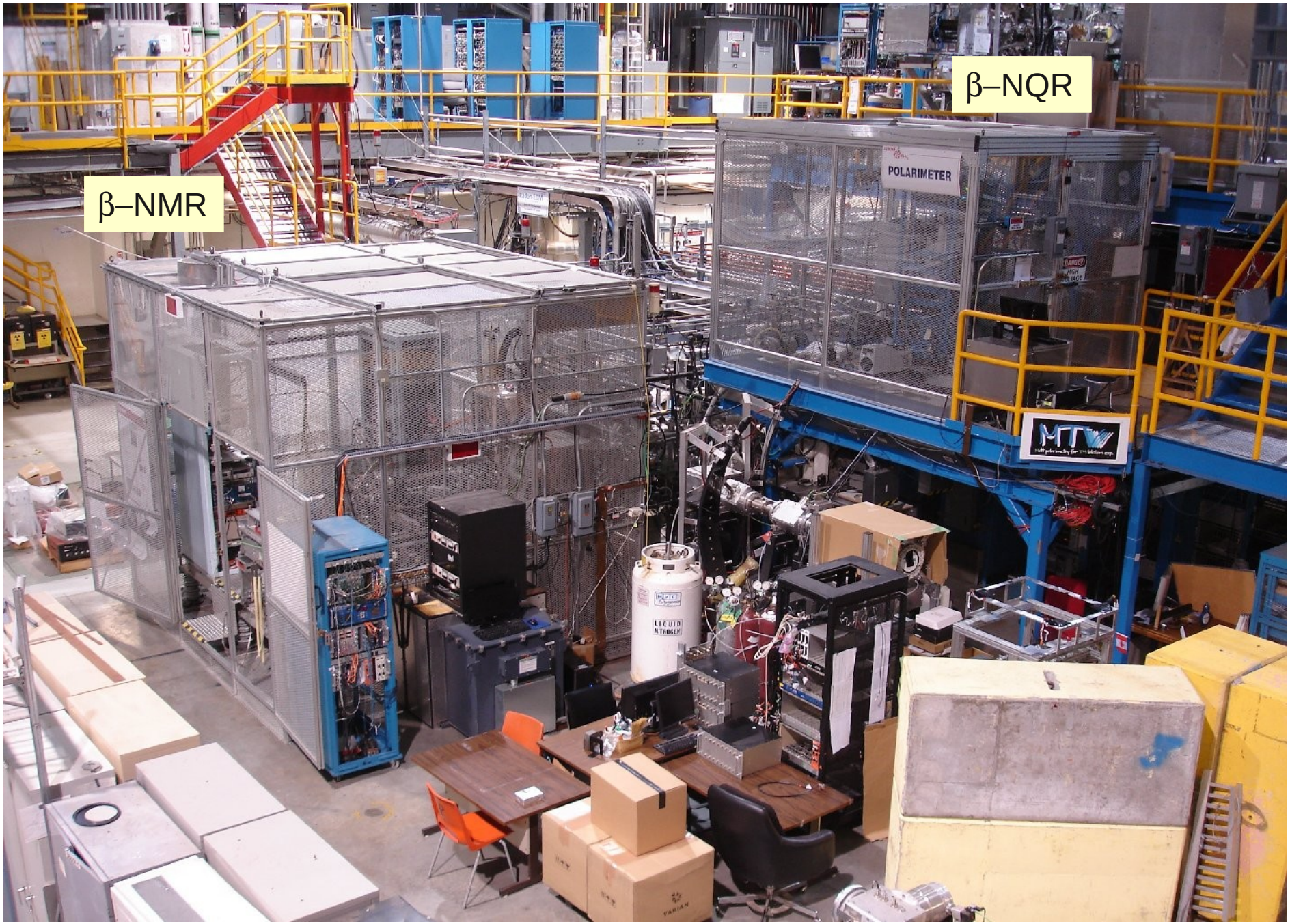
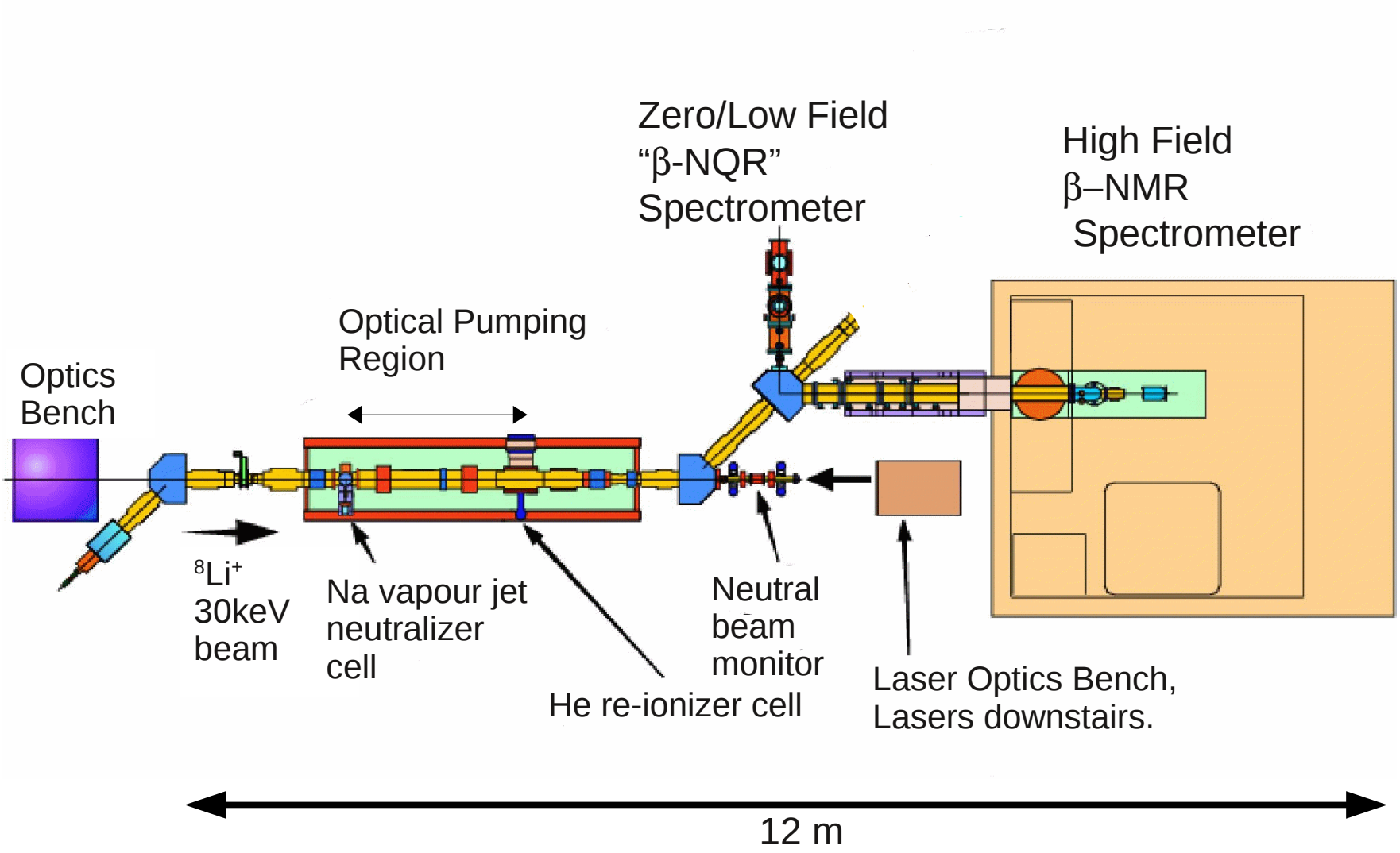
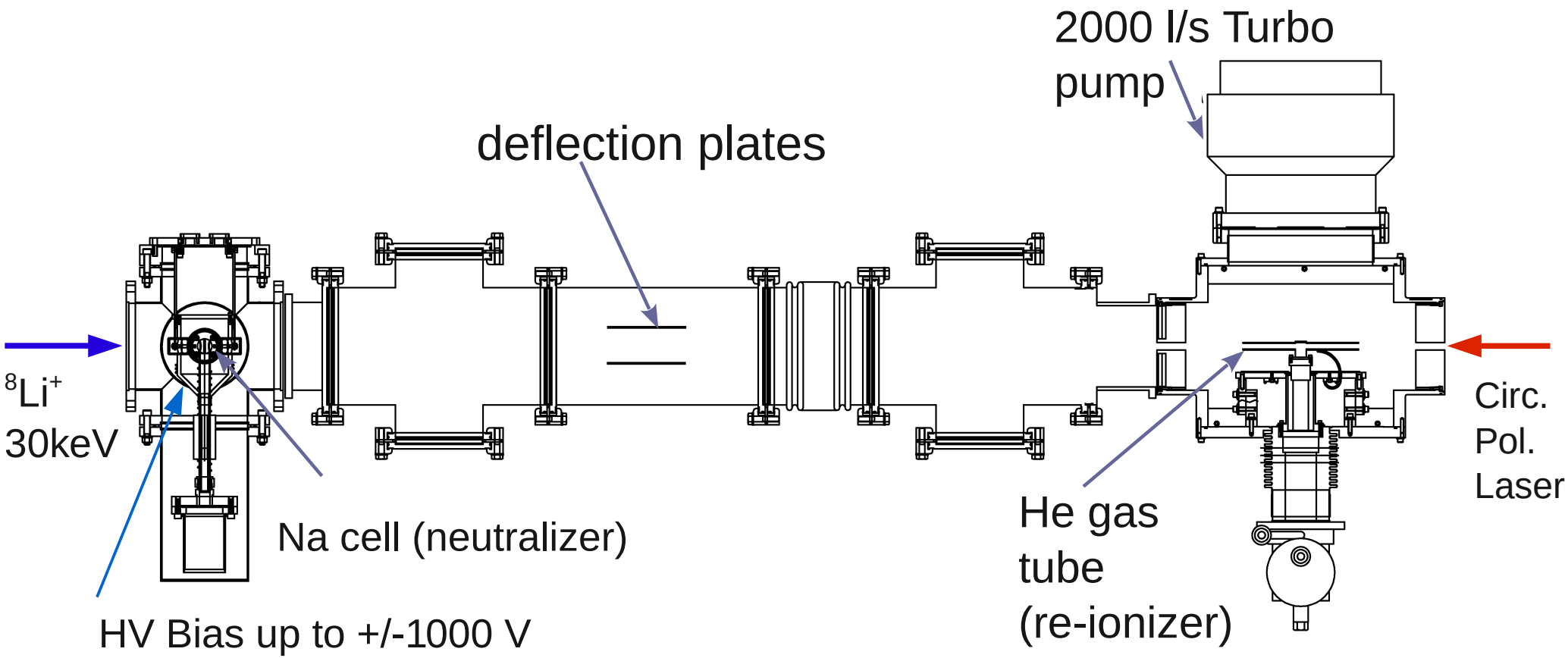
# High and Low-field Spectrometers in the ISAC-1 hall.



# Polarizer and High- and Low-Field β–NMR spectrometers

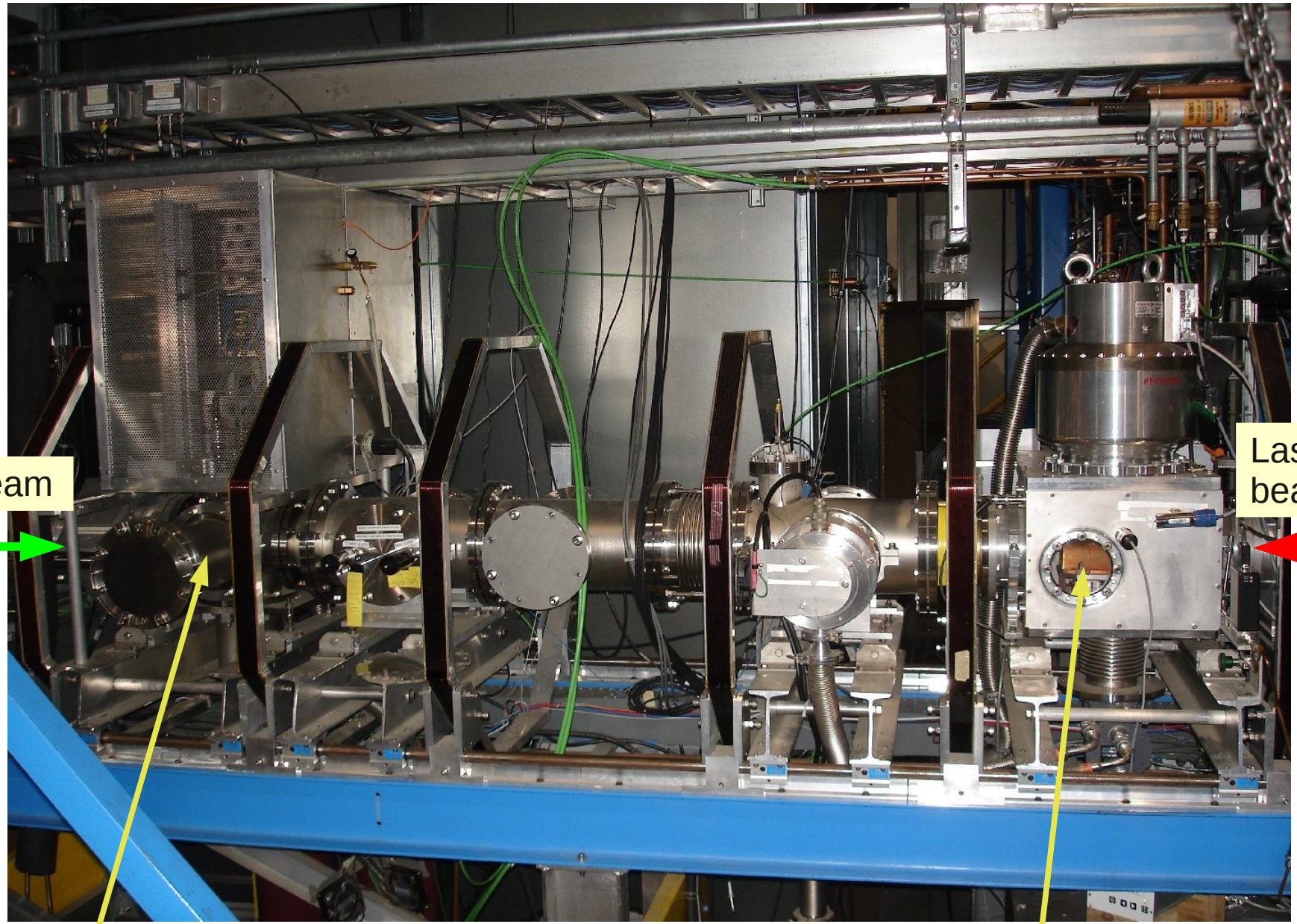


# Generation of $^{8}$Li nuclear polarisation via Optical Pumping



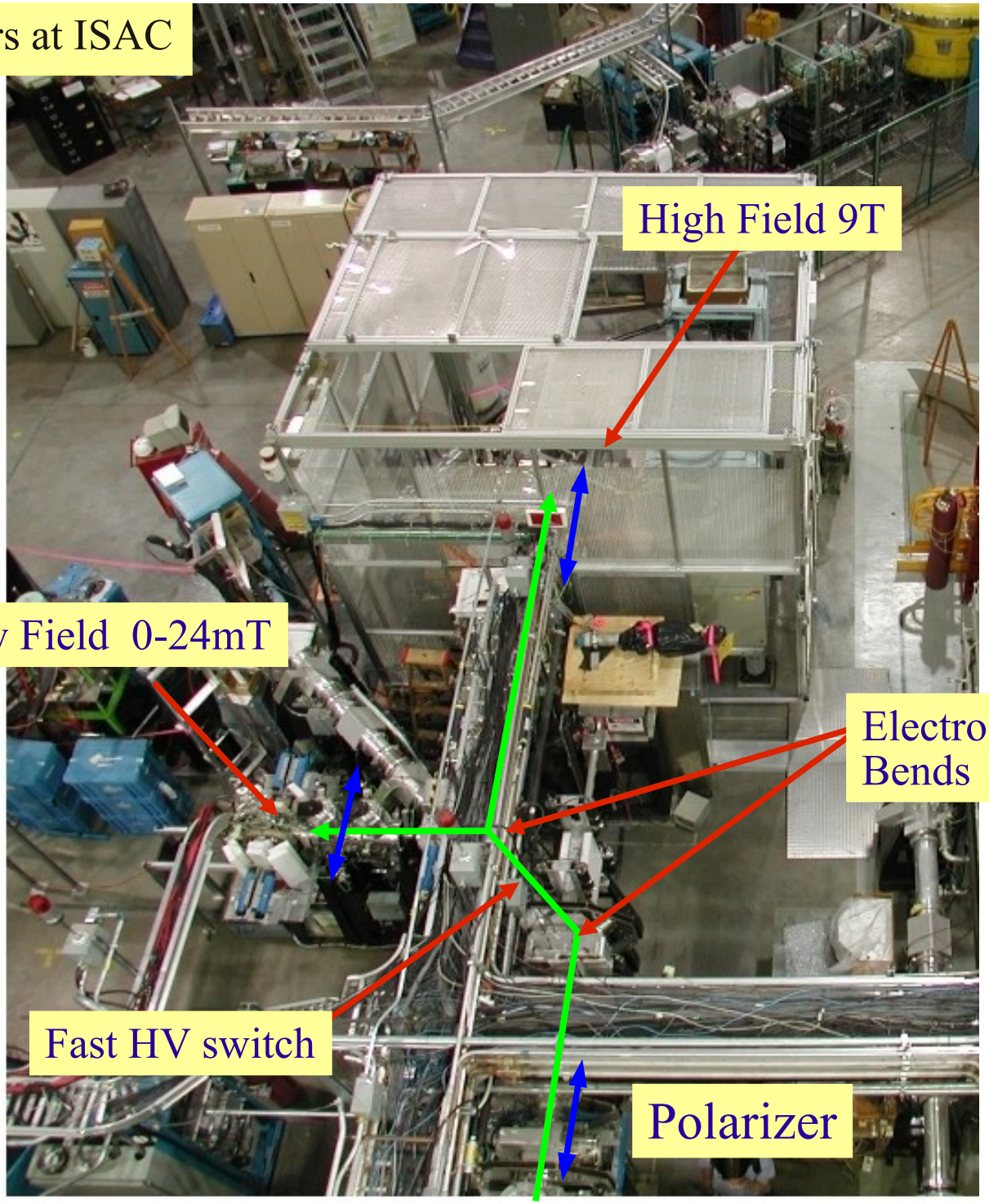

- Unpolarized $Li^{+}$ is neutralized by charge exchange in Na vapour.
- Neutral Li is optically pumped with circularly polarized light.
- Remaining charged fraction is deflected (removed) electrostatically.
- He gas strips one electron to yield spin-polarized $Li^{+}$ ion.
- Polarized ion beam is delivered to an experiment.

# Optically Pumped In-Flight Polarizer



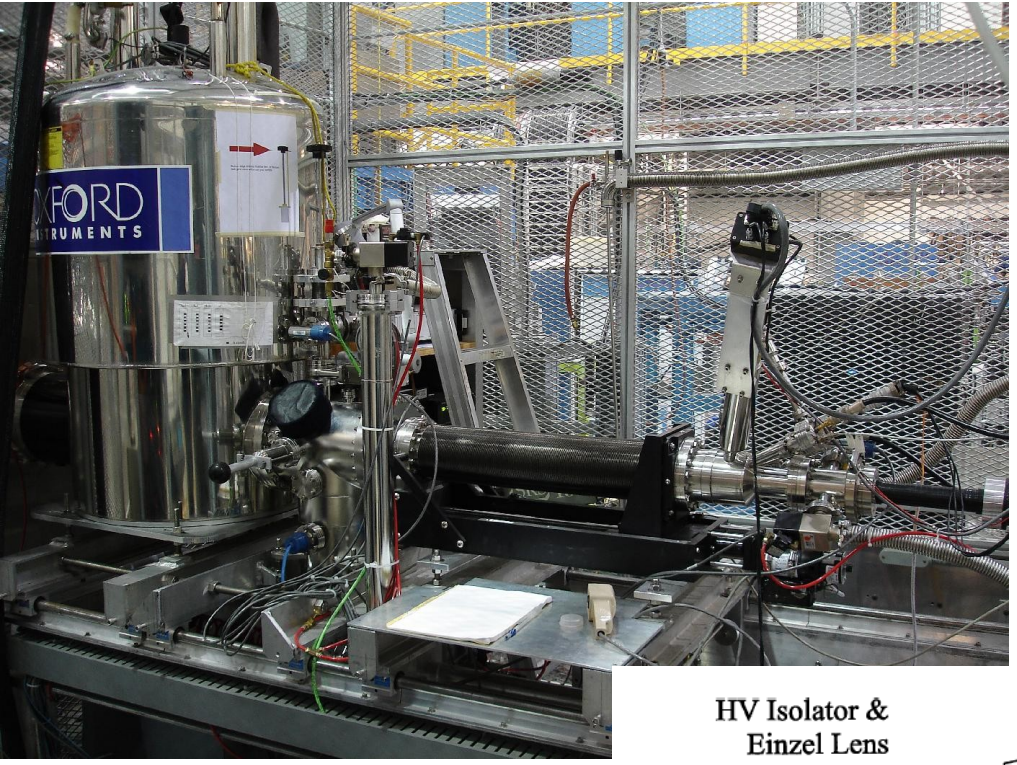
# βNMR Spectrometers at ISAC

(ca. 2005)




Fast HV switch kicks beam alternately to both spectrometers, permitting simultaneous operation.

# High Field NMR Spectrometer

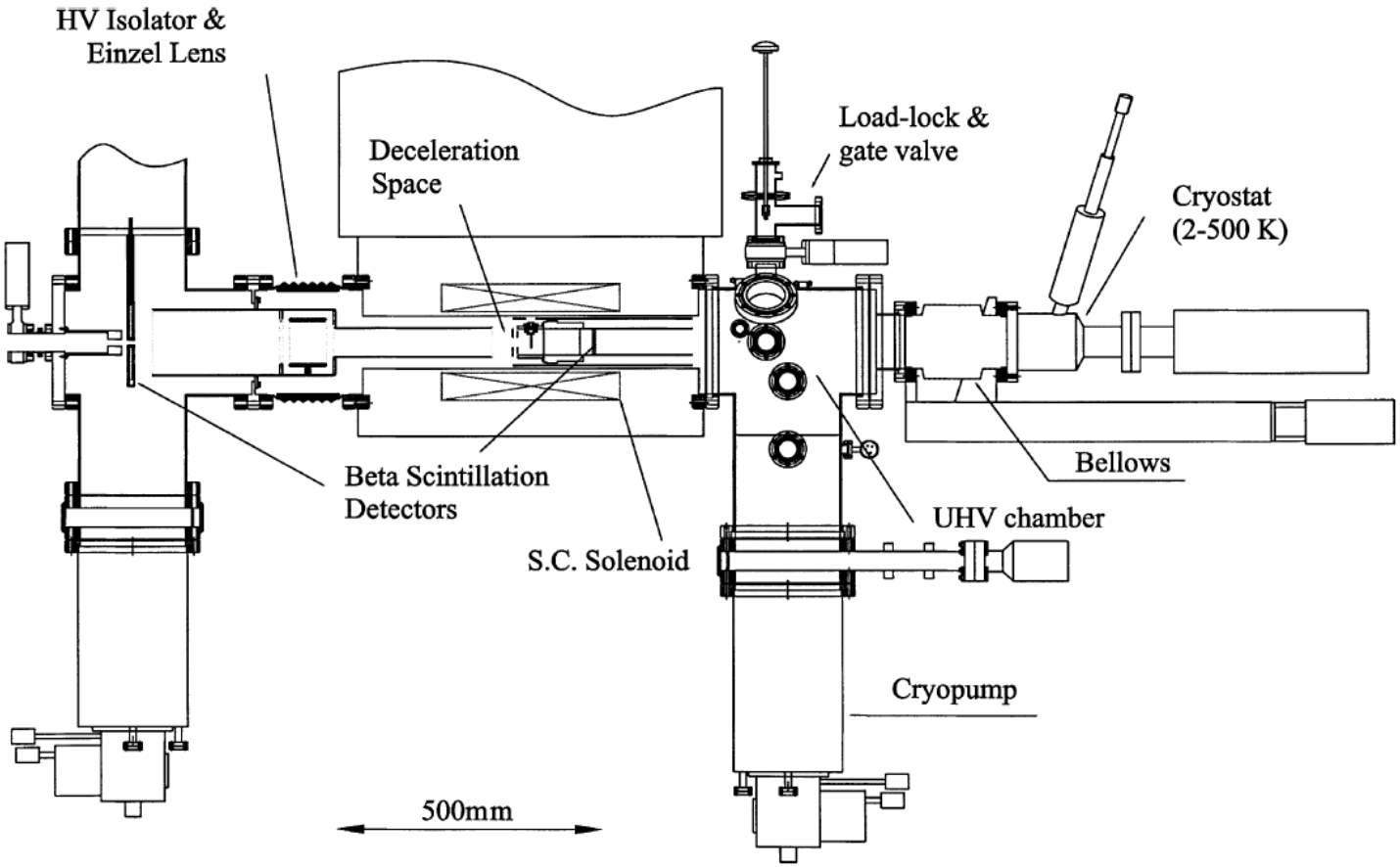



$H_0$ : 0.1 – 9 T

$E_{Li}$ : 0.1 – 30 keV

T : 3 – 300 K

Beam //
Magnetic
field

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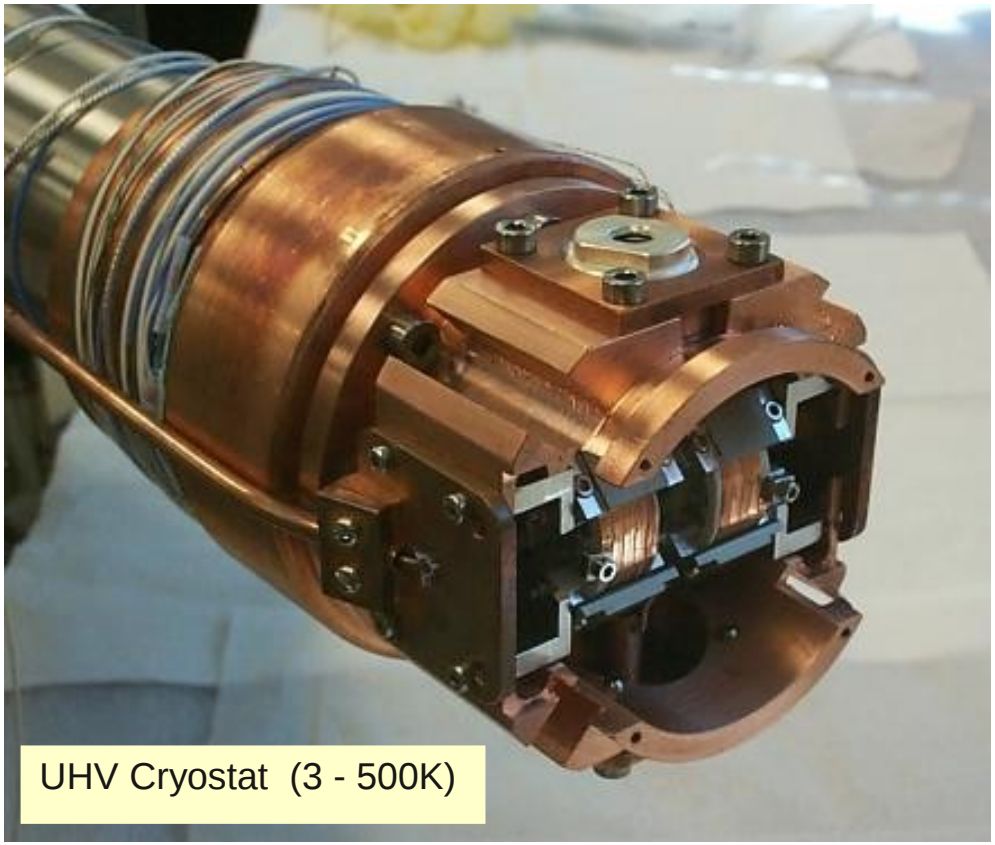
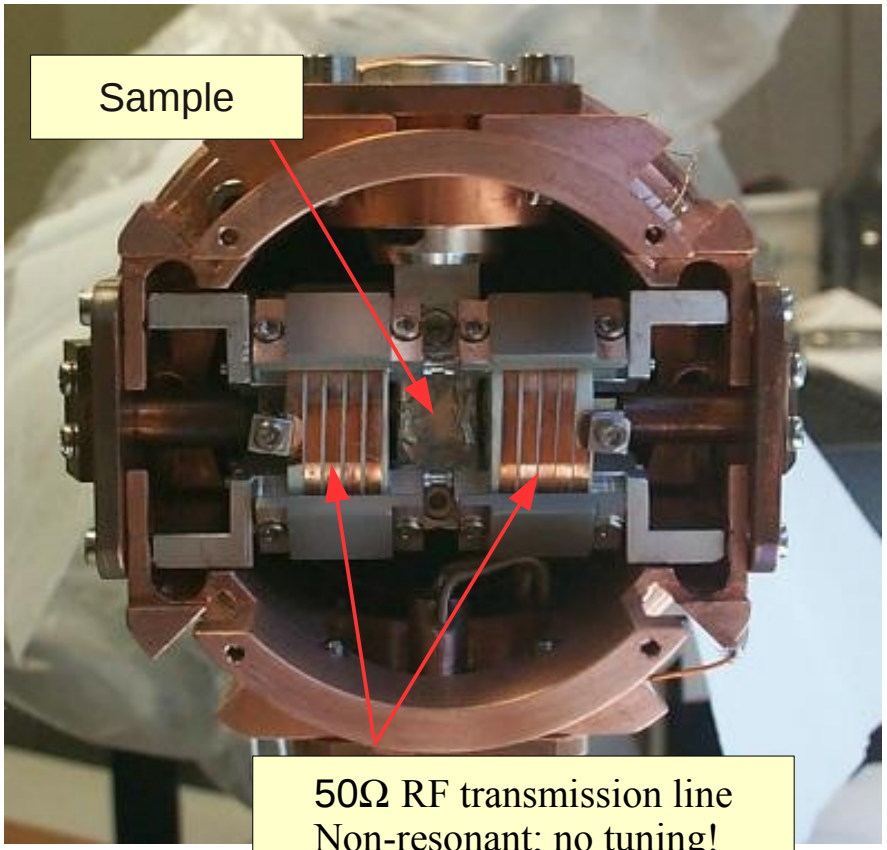
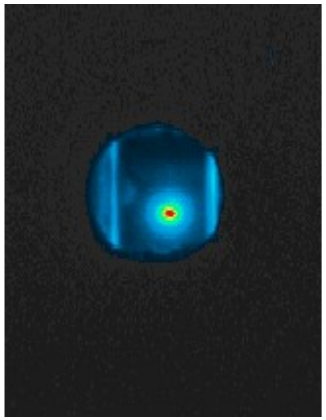
# High Field NMR Spectrometer




Sample holder

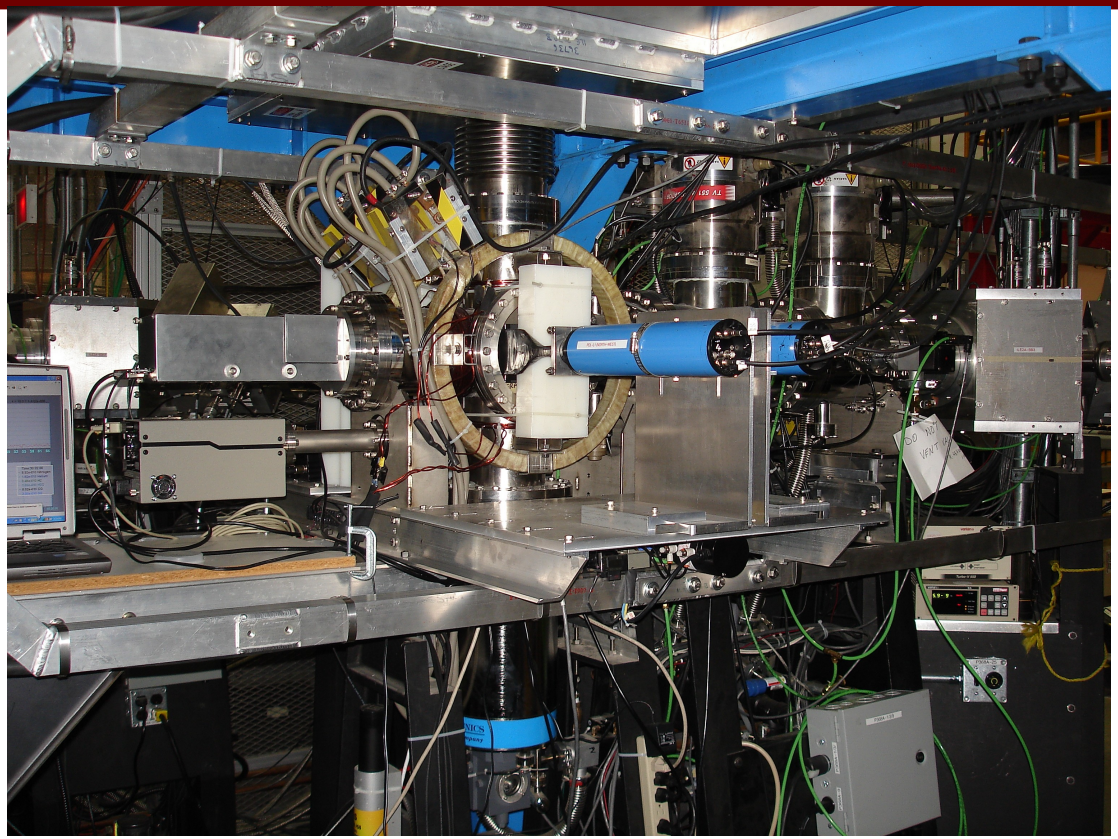


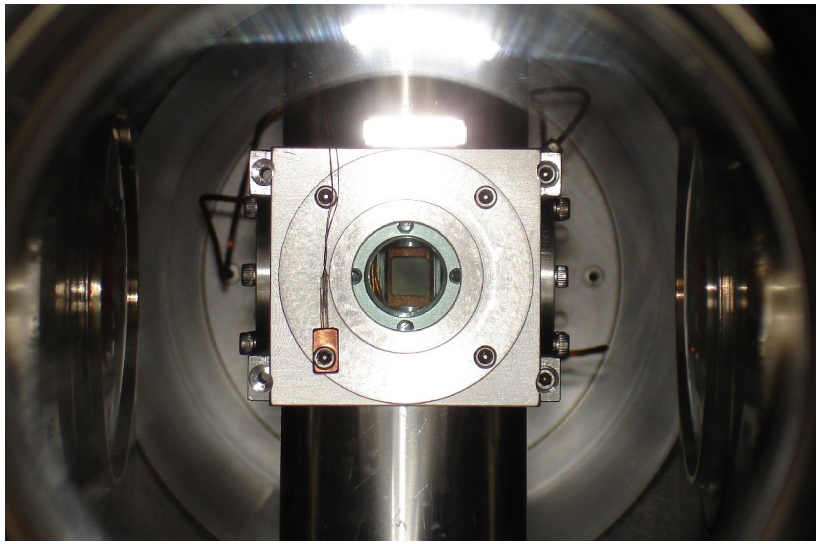
Diagnostics:
CCD image of $^{8}Li^{+}$ spot on scintillator.

$^{8}Li \rightarrow {}^{2}Be \rightarrow 2\alpha^{++}$

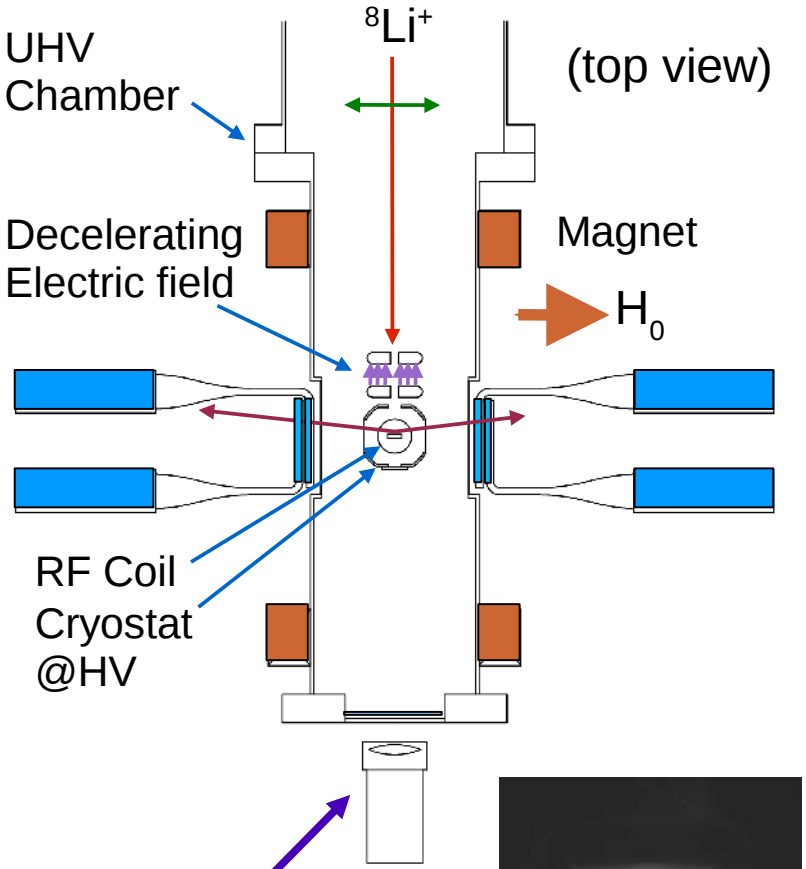
~2mm dia.

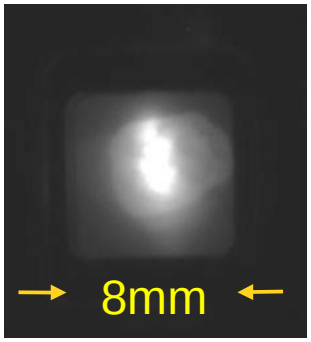
# Low & Zero Field NMR/NQR Spectrometer



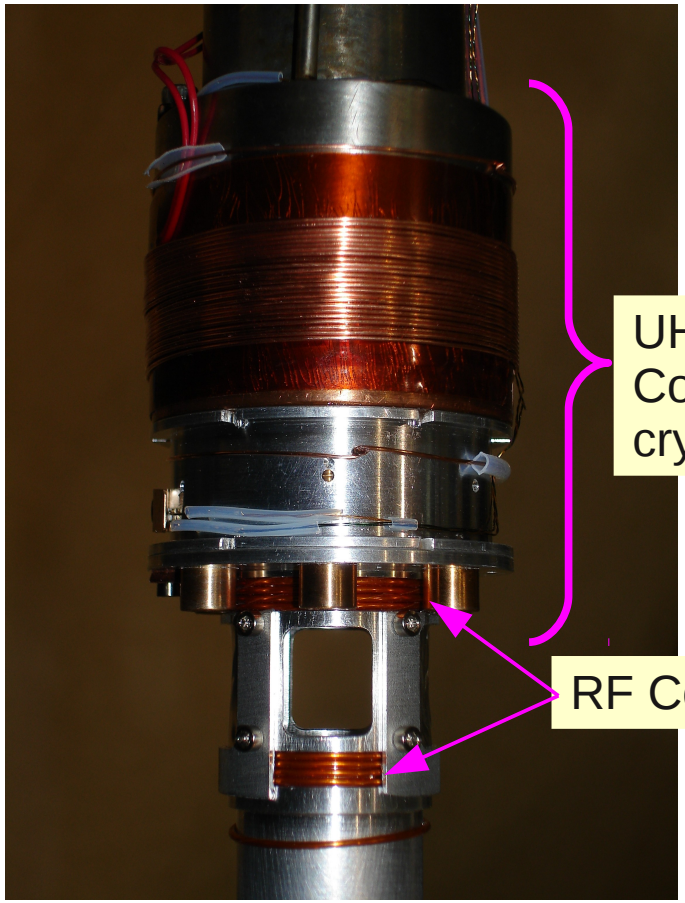


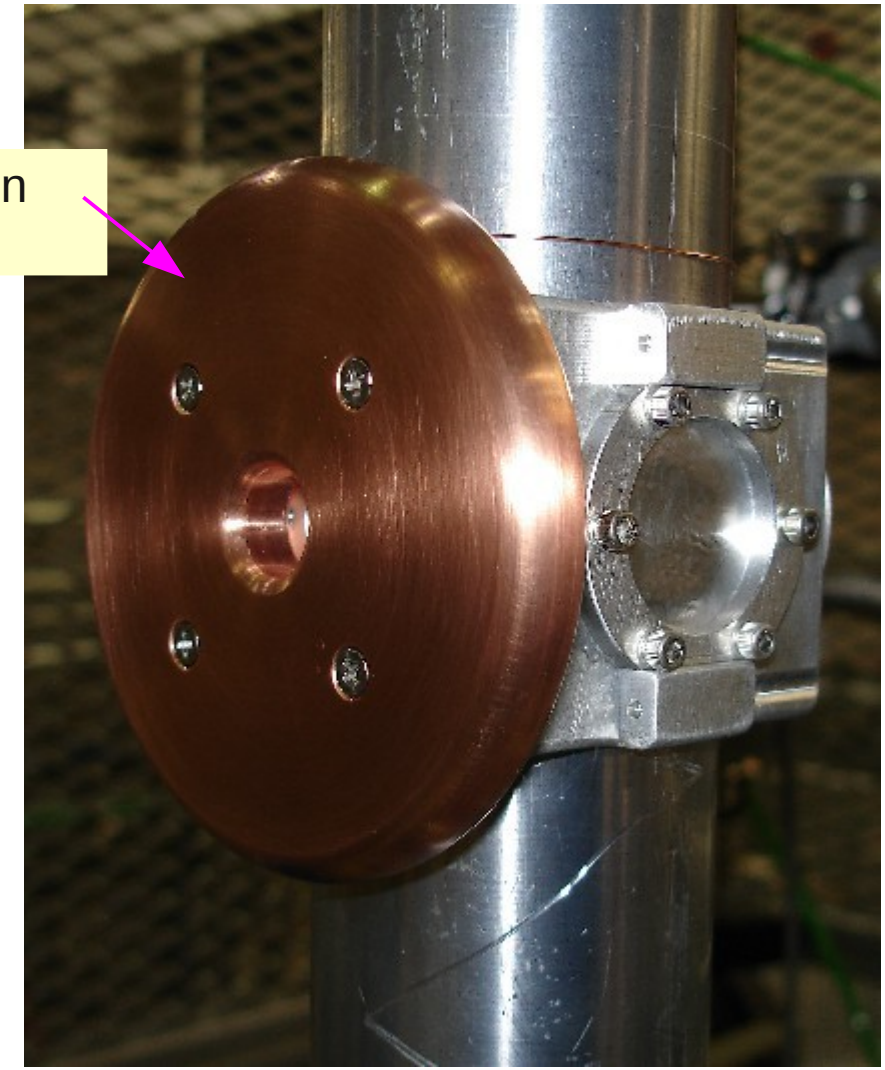
$\mu_0 H$ : 0 – 24mT
$E_{Li}$ : 0.5 – 30 keV
T : 3 – 300 K



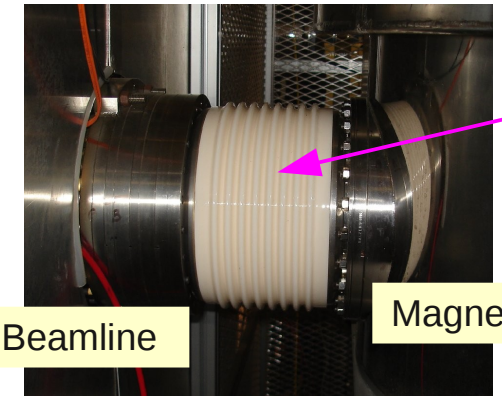



# Low & Zero Field NMR/NQR Spectrometer

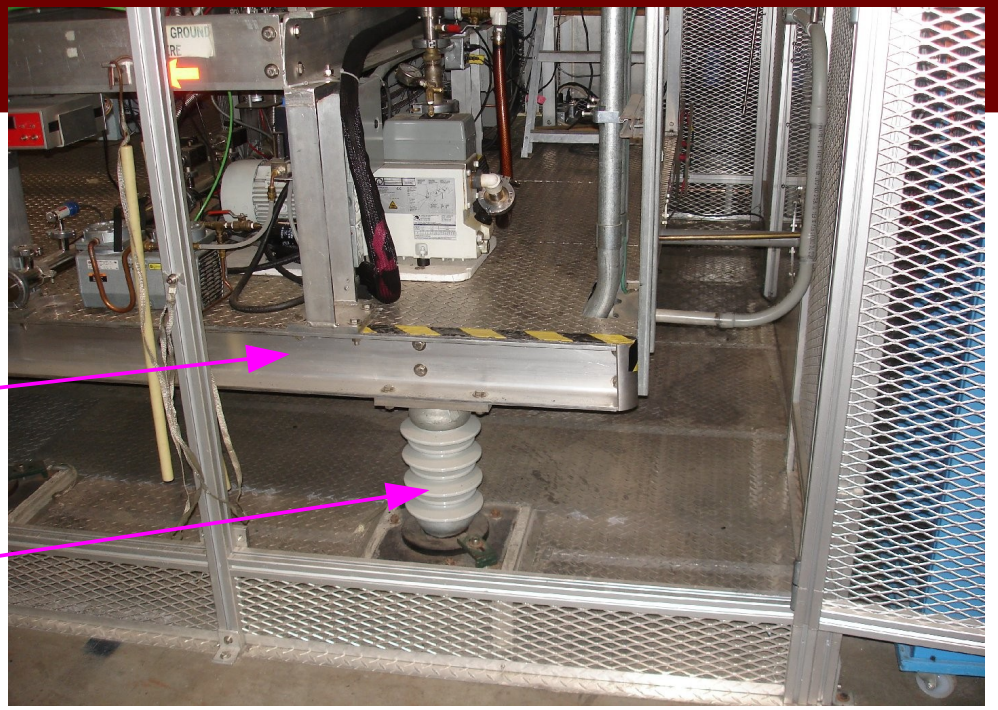


# HV Platforms

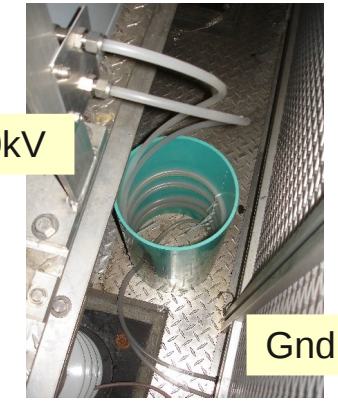



UHV ceramic break



Platform

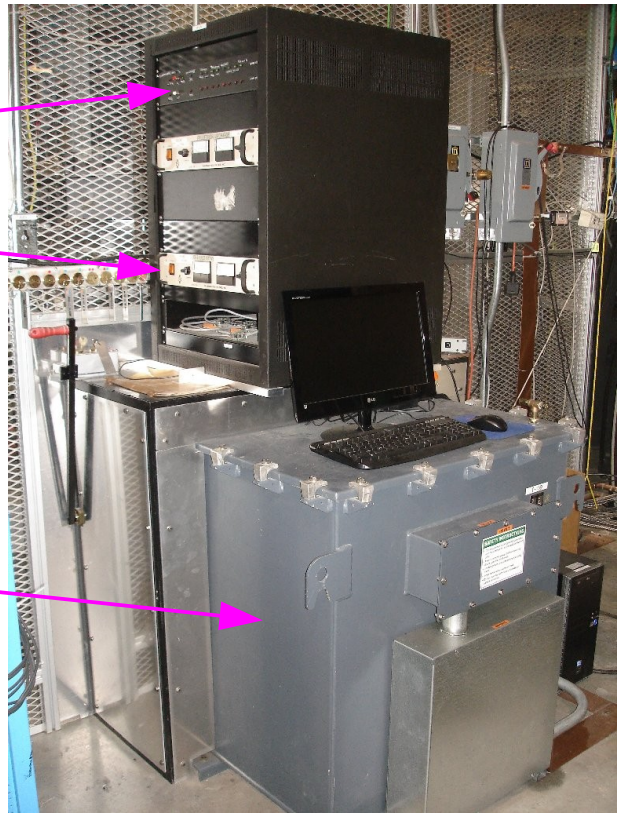
Supporting Isolators

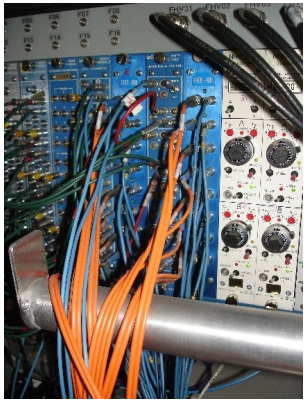



Cooling water

Safety Interlocks

HV bias supply

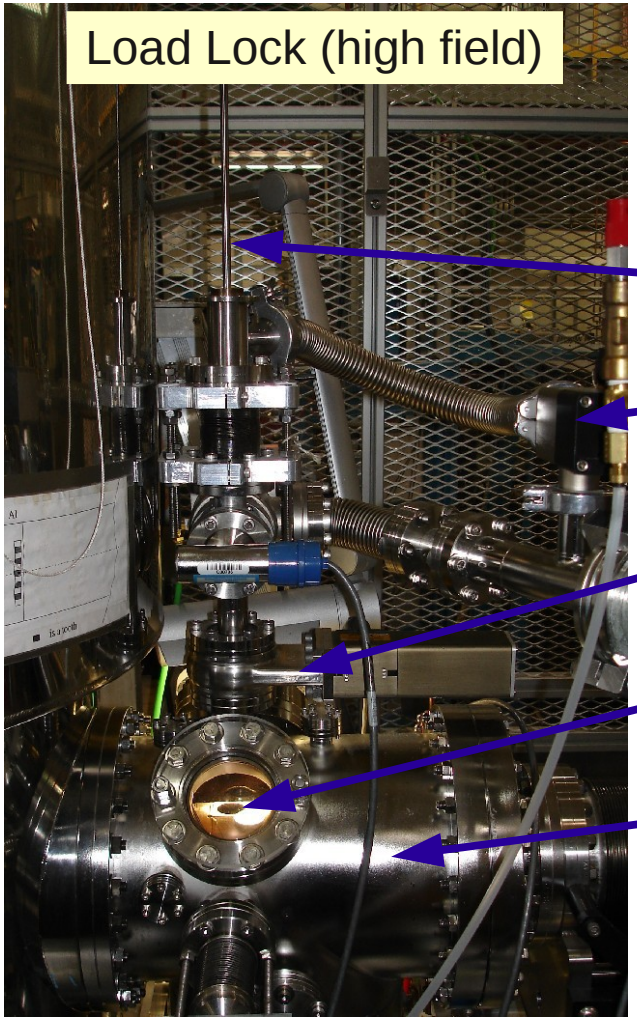




Network, signals over fibre.

Isolation power Transformer (60kW)

# Sample Handling



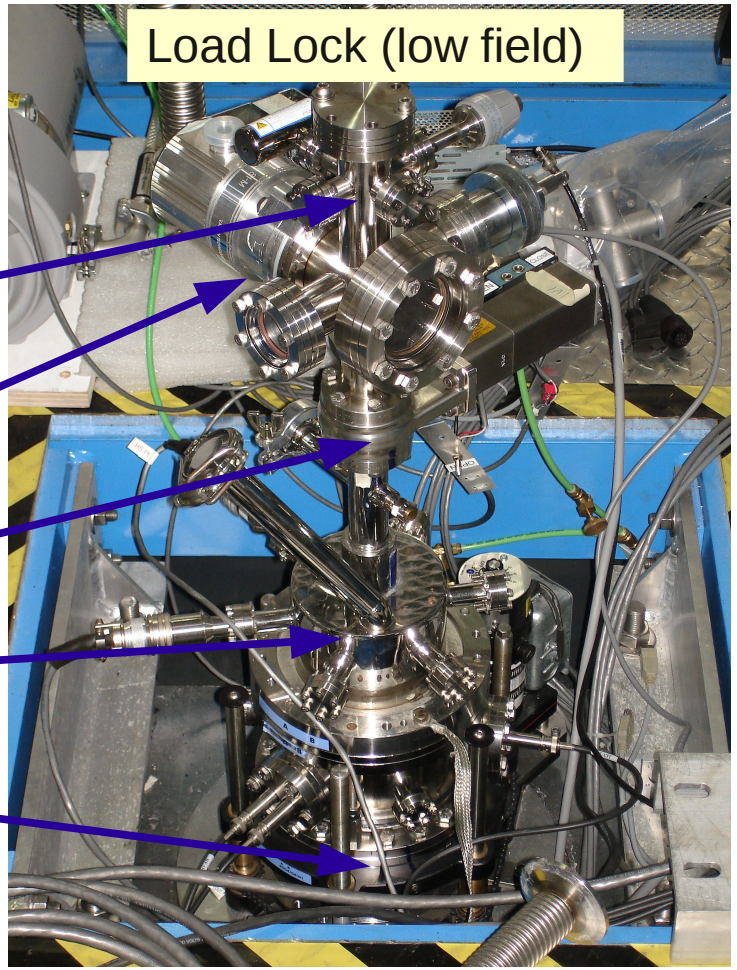

Load-lock chamber

High vacuum pump

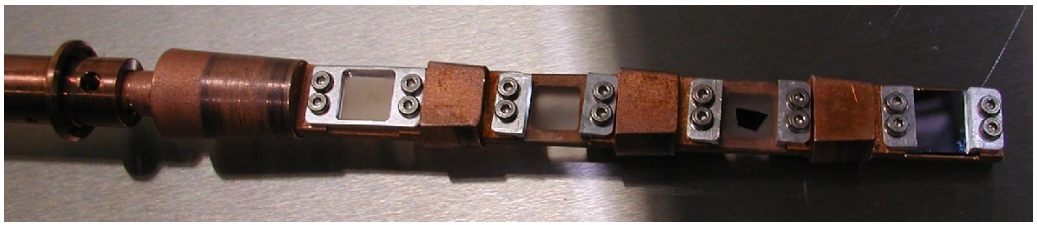
Isolation gate valve

Cryostat

UHV chamber



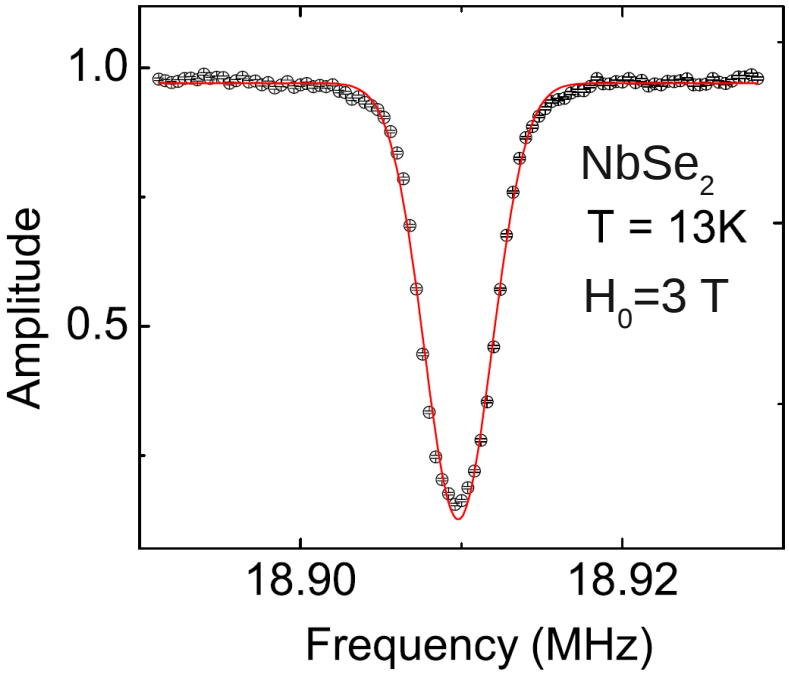

Multi-sample ladder
(fits Low field spectrometer via load lock)



# Types of measurements

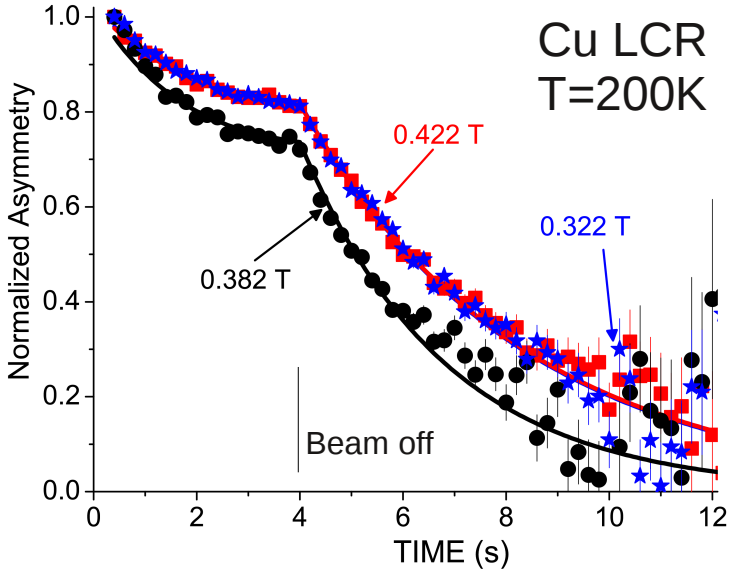
## Frequency scan ;

NMR and NQR with CW or modulated RF magnetic field, CW or pulsed beam.




## Time differential :

Measurement of spin-lattice relaxation rate $1/T_1$ with pulsed beams.




(No beam detector; $t_0$ is defined by beam kicker.)

## Independent variables :

Temperature, beam energy, applied DC and RF magnetic fields …

## Typical rates :

$2 \times 10^6$ events/s in detectors; runs typically 10 ~ 60 minutes each.

# Plans

Current injection : studies of transport of spin polarized electrons through interfaces. (without generating spurious magnetic field.)

In-situ sample surface preparation chamber.

Extended temperature ranges:

- $^3$He fridge to 0.3 K
- Oven to 500K.

Segmented APD detectors to handle higher rates.

More beam, eventually from ARIEL.

# Summary

β-NMR facilities at ISAC-I were constructed for studies in condensed matter physics, to complement our existing bulk μSR capability with a low energy probe, primarily $^{8}$Li.

Variable energy and stopping range (5 - 500nm) ⇒ **Depth-resolved probe of magnetism,** and more generally, able to study phenomena at surfaces of bulk materials and within thin film structures which affect the polarisation of the implanted probe.

Topics : superconductivity, disordered & dynamic magnetism, diffusion, structural transitions, transport...

**Two spectrometers :**

High field : $\mu_0 H_0$ = 0.1 ~ 9T (currently RF to ~45MHz), field normal to surface.

Low-field : $\mu_0 H_0$ = 0 ~ 0.024T, field in-plane.

Energy range 0.1 ~ 30keV at sample surface, with beam spot 1~ 3mm diameter.

Temperature range currently 3 ~ 300K (extended range 0.3 ~ 500K planned.)

**Types of measurements:**

NMR and NQR experiments in CW or pulsed & modulated RF magnetic field.

Measurement of spin-lattice relaxation rate $1/T_1$ with pulsed beams.

TRIUMF

Canada's national laboratory for particle and nuclear physics

Laboratoire national canadien pour la recherche en physique nucléaire

et en physique des particules

# Thank you!
# Merci!

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Montréal | Northern British Columbia | Queen's
Regina | Saint Mary's | Simon Fraser | Toronto
Victoria | Winnipeg | York

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# Some Isotopes for βNMR applied to Materials Science

| Isotope | Spin | $\tau_{1/2}$ (s) | $\gamma$ (Mhz/T) | Decay Asymmetry | Rates ($s^{-1}$) | |
|---|---|---|---|---|---|---|
| $^{8}$Li | 2 | 0.8 | 6.3 | 0.33 | $10^{8}$ | |
| $^{11}$Be | ½ | 13.8 | 22 | small * | $10^{7}$ | (* two decay channels) |
| $^{15}$O | ½ | 122 | 10.8 | 0.66 | $10^{8}$ | |
| $^{19}$O | 5/2 | 26.9 | 4.6 | 0.71 | $10^{8}$ | |
| $^{17}$Ne | ½ | 0.1 | ? | 0.33 | $10^{6}$ | |
| $\mu^{\pm}$ | ½ | $1.5\times10^{-6}$ | 135 | 0.33 | $10^{4}$ – $10^{9}$ | (at various labs) |

# Beta-NMR People at ISAC

***Local group :***

| | |
|---|---|
| Rob Kiefl | UBC Physics |
| *Masrur Hossain* | “ |
| *Dong Wang* | “ |
| Andrew MacFarlane | UBC Chemistry |
| *Terry Parolin* | “ |
| *Qun Song* | “ |
| Kim Chow | U Alberta |
| Gerald Morris | TRIUMF |
| Phil Levy | “ |
| Matt Pearson | “ |
| *Annika Voss* | U. Manchester |

***External PI's :***

| | |
|---|---|
| Sarah Dunsiger | Tech U. Munich |
| Elvezio Morenzoni | PSI |
| Hassan Saadaoui | “ |
| Zaher Salman | “ |
| Jun Sugiyama | Toyota CRDL |

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